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(54) Title: METHOD AND SYSTEM FOR CHILLING OF CARCASS PARTS AFTER SLAUGHTERING

(57) Abstract

The invention relates to a method for chilling of a carcass after slaughtering. The carcass is submerged into a chilling medium in the form of brine or slush ice with a temperature below 0 °C. The chilling may take place without shell freezing (temperature between –2 and –4 °C) or with shell freezing (temperature between –4 and –12 °C). Considerably less energy is required for this process than for traditional air chilling of slaughter–warm pig carcasses, and the process can be carried out in considerably shorter time.

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Method and system for chilling of carcass parts after slaughtering.

The present invention relates to a method and a system for chilling of carcass parts after slaughtering.

The suitability of a chilling method for chilling of a certain product is determined by such factors as the type of chilling medium, working temperature for the chilling medium, the flow profile around the product to be chilled, the orientation of the product in proportion to the flow, the weight and shape of the product, the sensibility of the product to cold shock and freezing, the initial and final temperatures, and time available. If these factors do not interact, the method is unsuitable for chilling of the product in question.

Today pig carcasses are chilled with cold air in an intensive process wherein half pig carcasses, suspended in pairs from a gambrel, are led through a chilling room while cold air is being blown onto the carcasses. The intensive air chilling (the so-called tunnel chilling) distinguishes itself by a low chilling loss and PSE-frequency. The intensive air chilling of pig carcasses is fairly rapid compared with the commonly used batch-wise chilling process, but it is also more energy consuming.

The purpose of the invention is to provide a new method for chilling of carcass parts after slaughtering, which method requires considerably less energy than the above mentioned process. Preferably, the method should also make possible a shortening of the chilling time.

The method according to the invention is characterized in that the carcass parts are submerged into a liquid chilling medium with a temperature below 0 °C, that a relative movement between the chilling medium and the carcass parts is provided, and that the carcass parts, after having given off a desired quantity of heat to the chilling medium, are lifted from the chilling medium and then allowed to equalize differences in temperature.

In the present description, a liquid chilling medium is to be understood as a brine on an aqueous basis or slush ice.

The method according to the invention has significant advantages compared with the intensive air-chilling method (tunnel chilling) for chilling of carcass parts. It requires much less energy. It has proved that the consumption of energy can be reduced by approx. 50% compared with traditional, intensive air chilling of carcasses. In addition, the method of the invention makes it possible to shorten the chilling time by up to 30 % for slaughter-warm pig carcasses providing shell freezing of the carcasses. The method of the invention is much faster compared with the commonly used batch chilling of carcasses.

A further advantage of the method of the invention is that it is unnecessary to take special flow-related precautions to achieve good heat transfer from the carcass part to the chilling medium. By a velocity of the relative movement between the chilling medium and the carcass parts of between 0.05 and 0.2 m/s chilling times for e.g. half pig carcasses of 60 minutes or less can be achieved. This velocity can be provided by conveying the half carcasses through the chilling medium at the usual transport velocity of a slaughter line.

The chilling medium used (brine or slush ice) has a high cooling capacity and high conductivity of heat which makes it possible to use higher working temperatures as the transmission of heat is much higher compared with air.

In the present description, brine is to be understood as aqueous solutions of solids, e.g. salts, or mixtures of water and organic liquids, e.g. glycols and alcohols. Brine has the quality that it is frost-proof at temperatures below 0 °C, and it can e.g. work at -7 °C without freezing.

While rising in temperature, the brine removes the heat of the product, and therefore it is necessary to cool it in a refrigerator. An advantage in using brine is that it is easy to cool down in an external refrigerator.

In the present description, slush ice is to be understood as a liquid in the form of an aqueous solution of solids or a mixture of water and organic liquids, which liquid contains ice in the form of particles. The particles may have a round shape (e.g. globules). Slush ice has the quality that it remains flowable at temperatures below 0 °C (at the working temperature). Preferably, the slush ice does not contain a larger amount of ice than it will remain of low

viscosity and can be pumped without difficulty. Preferably, the slush ice used contains fine ice particles which remain floating, see e.g. WO-A1-9627298 (Dansk Teknologisk Institut).

The heat energy of the carcass parts which is absorbed by the slush ice causes a phase change of ice to water, and therefore slush ice has a large cooling capacity. Slush ice has excellent thermic properties (latent heat of fusion) and it also shows good mixing properties (keeps itself homogeneous and fluidized).

Slush ice is a binary mixture which in practice is zeotropic, i.e. that phase change from solid to liquid state takes place in a temperature interval at the freezing point of the mixture.

Slush ice offers a number of advantages compared with brine, such as better operating economy, possibility of energy storage and less strain on the environment (higher COP-value; COP = coefficient of performance (kW-chilling per kW-power consumption)). Because of the content of ice in the slush ice, a very large cooling capacity can be stored in a relatively smaller volume. This makes production of cooling capacity possible during the night hours when the electricity rate is low. It will typically be possible to operate at night at lower condensing temperature, with a consequent improvement of the COP-value, and the compressor can work at constant and optimum conditions. Night operation means that it is only necessary to invest in half the refrigerating capacity, as the same amount of cooling capacity can be produced in twice as long time.

Even if night operation is not used, the slush ice has the advantage that smaller quantities are to be circulated compared with brine.

According to the invention the chilling medium in the form of brine or slush ice works in the temperature range of below 0 °C, which in practice is -1 °C or below, preferably between -2 and -20 °C. It has proved especially advantageous to work with a chilling medium with a temperature of between -2 and -4 °C and to set the velocity of the relative movement to mainly prevent shell freezing. Alternatively, the temperature of the chilling medium may be between -4 and -12 °C to provide shell freezing. In these embodiments the energy consumption is low and a satisfactory process time is achieved.

Preferably, a velocity of the relative movement between the chilling medium and the carcass parts of between 0.02 and 1 m/s is used, preferably between 0.05 and 0.2 m/s, which velocity is preferably provided by leading the carcass parts, suspended from a suspension conveyor, through a vessel containing the chilling medium. By such a forced convection around the carcass part a sufficient heat transfer is achieved to chill the part very quickly.

The carcass parts are preferably enveloped individually in a foil before they are submerged into the chilling medium, which foil is drawn closely to the surface of the part by evacuation of air from inside the foil. In this way the chilling medium and the carcass parts are kept separated from each other during the chilling process by means of the foil, which prevents the carcass parts from exchanging substances with the chilling medium. When the carcass parts are enveloped individually in foil, cross contamination between the carcass parts is avoided. Furthermore, the carcass parts do not lose weight when they are enveloped in a foil.

Foils or films of plastic, textile or rubber having thicknesses up to 1 mm can be used. Plastic and textiles have heat conducting properties which correspond by and large to those of the carcass parts. This means that the envelopment in thermophysical connection adds only the thickness of the foil to the carcass parts, provided the foil fits closely against the surface. A polyethylene foil with a thickness of 0.15 mm has proved to possess sufficient strength and flexibility to be stretched over carcass parts with protruding legs, e.g. half pig carcasses with their heads cut off. Polyethylene is the most widely used material for packaging of meat and meat products.

To avoid or reduce the occurrence of air between the foil and the surface of the carcass part, the air is sucked out of the carcass part envelopment. For this purpose tubes can be used, which are inserted at the places where air pockets frequently occur. The air is sucked out until the foil fits closely to the carcass part at as large an area as practically possible. The envelopment can be closed tightly before the chilling process starts by submerging the enveloped carcass part into the chilling medium.

The foil envelops the carcass while it is in the chilling bath. The chilling medium presses the foil tightly against the carcass, ensuring an effective heat transfer from the carcass part to the chilling medium.

In order to reduce the water activity of the surface the carcass parts can be exposed to partial drying prior to being enveloped in a foil, so that the chilling in the chilling medium afterwards can take place under such conditions that the carcass parts are shell frozen without a risk of discoloration.

The slaughter lines of slaughterhouses usually convey the half carcasses in pairs suspended in gambrels. During the envelopment of such half carcasses and the transport of the carcasses through the chilling bath, the half carcasses can remain on the gambrels so as to retain the identification.

The carcass parts can be submerged into the chilling medium by means of e.g. a vertical cylinder which lowers the gambrel or a fixture with the gambrel so that the carcass parts are immersed in the chilling bath. The bath can be contained in a large vessel in which the carcass parts are led around in a predetermined path by means of e.g. a chain conveyor keeping a fixed distance between the gambrels or the fixtures for these.

After the chilling process the carcass parts are lifted from the chilling bath, e.g. by means of another cylinder. By applying a pressure slightly above that of the atmosphere inside the envelopment, the foil will be released from the carcass part and it can be removed. The gambrel with the half carcasses can then be transferred to the usual overhead or transport conveyor and be sent further on to a temperature equalizing room for equalization of differences in temperature. During equalization the average temperature of the carcass parts may be reduced (e.g. by 1 to 5 °C) due to cold air in the room for equalisation.

As solid in the brine or the slush ice a salt, such as NaCl, can be used. As organic liquid an alcohol or glycol can be used. By changing the quantity or the type of additive, the working temperature of the brine or the slush ice can be adjusted in order to ensure that no essential freezing of the brine or essential thickening of the slush ice takes place at this temperature.

As chilling medium is preferably used slush ice based upon an aqueous NaCl solution or a mixture of water and ethanol.

An aqueous NaCl solution has good thermal properties (slightly poorer than those of water), but due to corrosion, the use of it makes demands on the environment in which the chilling medium is to be used. An aqueous solution containing approx. 20 % NaCl is frost-proof down to -15 °C.

An aqueous solution of other less corroding salts can be used, e.g. a potassium acetate solution, which has slightly poorer thermal properties, but which is attractive as a chilling medium because of the low freezing point and non-toxicity of the solution.

An aqueous calcium chloride solution with 18,5 weight percent calcium chloride is frost-proof down to -15 °C. The solution is corrosive. A non-corrosive solution of this type has the trade name of Kølsator. A calcium chloride solution is very cheap and suitable for use in connection with foods. The cooling capacity is 5 to 10 % less than that of NaCl-solutions.

A frost-proof potassium acetate solution can e.g. be made by means of the commercial product Aspen Temper -20. The solution possesses good thermophysical properties, and according to statements from the manufacturer, it can be used with foods.

A mixture of propylene glycol and water with 33 weight percent propyleneglycol is frost-proof down to -15 °C. The thermophysical properties of the solution are poorer than those of water, especially as to dynamic viscosity and volume-specific heat capacity.

A mixture of ethanol and water with 25 weight percent ethanol is frost-proof down to -15 °C. The thermophysical properties are poorer than those of water, but better than those of propylene glycol.

The latent heat of fusion in slush ice causes a higher heat-transfer coefficient and lower volume flow than by the use of a brine. For slush ice heat-transfer coefficients have been measured that are two to three times higher than for brines. The excellent heat-transfer

coefficients for slush ice are particularly achieved by an ice content of more than 15 weight percent. The viscosity is higher than for brines. The pressure loss in circulating slush ice increases regularly with the content of ice, until an ice content of approx. 30 weight percent. The increased pressure loss in proportion to the use of brine is to be seen in the light of the fact, however, that the circulating quantity is reduced considerably because of the utilization of the latent heat of fusion in the slush ice. The total result is a reduced requirement for pump effect. Slush ice may be pumped with traditional centrifugal pumps.

Preferably, slush ice with an ice content of max. 35 weight percent is used, especially 10-30 weight percent.

The good heat-transfer coefficients for slush ice may be used to reduce the process time.

According to an embodiment, the chilling medium may contain NaCl which constitutes more than 15 weight percent when the medium is a brine and 2 to 15 weight percent when the medium is slush ice.

According to another embodiment, the chilling medium may contain 5 to 25 weight percent ethanol.

The chilling medium can advantageously be cooled down in a one-stage refrigerator, which saves considerable quantities of energy compared with two-stage refrigerator, which is used in tunnel chilling systems.

Preferably, the method of the invention is carried out under such conditions that an external heat-transfer coefficient for the carcass parts of between 150 and 2500 W/m^2K is provided, particularly between 300 and 1000 W/m^2K. When the parts are chilled with shell freezing the thermal properties of the frozen layer change, and a large cooling quantity is stored in the frozen shell. For the same equalized temperature the chilling time is therefore shorter than without shell freezing. Shell freezing is freezing of the outer layer of the carcass part, e.g. the outermost 1 to 5 mm of the carcass part. Meat freezes at temperatures of between -1.8 and -6 °C.

Preferably, the carcass parts are shell-frozen pre-rigor to a given maximum depth (e.g. a few mm) which will keep the meat quality.

After the carcass parts have given off to the chilling medium the quantity of heat corresponding to the wanted terminal temperature, they are lifted from the medium and allowed to equalize differences in temperature.

In a special embodiment the chilling of the carcass parts is continued in the chilling medium after equalization (post-rigor) until the parts are frozen through.

The method according to the invention is used with particular advantage for chilling of whole carcasses, preferably pig or cattle carcasses, or carcasses of sheep or lamb, or large parts thereof, such as half or quarter carcasses, but it can also be used for chilling or post-chilling of small parts, like course cut-ups, e.g. fore-ends, middles and hams. The method according to the invention can also be used for post-chilling of boned meat and cuts.

The system of the invention for chilling of carcass parts after slaughtering is characterized in that it comprises a vessel, means of transportation to lower into the vessel carcass parts being conveyed along a transport path, means of transportation to provide a relative movement between the carcass parts and a liquid chilling medium in the vessel, a refrigerator designed to cool the chilling medium, means of transportation to lift the carcass parts from the vessel, and means of transportation to convey the carcass parts to an area designed for temperature equalization of the carcass parts.

The means of transportation to provide a relative movement between the carcass parts and a liquid chilling medium in the vessel may comprise a conveyor which carries the carcass parts through the vessel.

The system of the invention may comprise an arrangement which, before the carcass parts are lowered into the vessel, envelops each carcass part into a foil and draws the foil closely to the surface of the part by evacuating the air from inside the foil, and another arrangement which removes the foil from the carcass part after it has been lifted from the vessel. Up-stream of

the arrangement the system may comprise an equipment for partial drying of the carcass parts which are being conveyed along the transport path.

The refrigerator for cooling down of the chilling medium may be a one-stage refrigerator.

The vessel may contain a brine on an aqueous basis or slush ice as chilling medium for the carcass parts.

The system may comprise a slush-ice generator.

The invention is explained in further detail in the following examples.

Example 1

Heat-tranfer coefficient of half pig carcasses

The purpose of this example is to examine the importance of the flow velocity of the chilling medium for the external heat-transfer coefficient of half pig carcasses. The external heat-transfer coefficient is essential for the chilling of carcasses, as the process time increases when the transfer coefficient is falling. An essential condition for using new methods for chilling of pig carcasses is that the heat-transfer coefficient is sufficiently high to provide an acceptable chilling time.

Examinations according to the present example have shown that by use of a liquid chilling medium with a temperature below 0 °C it is not only possible to achieve advantageous chilling times, but the chilling proces can also be performed without special flow-technical arrangements. Brine or slush ice is used as a chilling medium with a temperature below 0 °C.

Process times of 60 minutes or less can be achieved, e.g. 35-50 minutes, with a moderate forced convection around the carcass, e.g. with a flow velocity for the chilling medium of between 0.2 and 0.5 m/s.

A sufficiently high external heat-transfer coefficient between the chilling medium and the carcass is an essential precondition for obtaining short chilling times. The coefficient depends upon the chilling medium and the flow profile, including the orientation of the pig carcass in proportion to the flow.

Based on model tests the following heat-transfer coefficients have been calculated for half carcasses which are chilled in brine or slush ice with forced convection:

Flow velocity (m/s)	**Brine**	**Slush ice**
	Heat-transfer coefficient (W/m^2K)	
0.1	500	1050
0.2	800	1630
0.5	1660	3070
1.0	2900	5175

The table shows that slush ice provides external heat-transfer coefficients that are approx. twice as high as those of brine, in spite of the fact that slush ice has three times as high a viscosity as brine. So the disadvantage of a higher viscosity has been more than compensated for by the high Prandtl-number and heat-transfer properties of the slush ice.

The conveyor of a slaughter line typically has a speed of approx. 0.1 m/s. If carcasses at this speed are led through the chilling medium in the form of brine or slush ice, a sufficiently convective contribution is obtained to provide reduced chilling times.

When a mixture of ice and water is used as chilling medium (i.e. using a temperature of 0 °C) the same chilling times should be expected as in tunnel chilling of pig carcasses. The thermic properties of meat is the main restriction to energy transport when the heat-transfer coefficient is greater than approx. 500 W/m^2K.

Example 2

Importance of chilling medium to chilling rate

The purpose of this example is to examine the influence of different parameters on the chilling of a dummy which is a representation equivalent to a warm, half pig carcass. The dummy is heated to a temperature of 35 °C in a heating bath and is chilled by submersion into a chilling medium in the form of brine or slush ice. The chilling mediums are based upon ethanol and water. The effect of the following parameters is examined: The flow velocity of the chilling medium in proportion to the dummy, the temperature of the chilling medium, and the ice content in the slush ice.

As a low level of flow velocity is selected 0.05 m/s. This corresponds mainly to the chain velocity of existing tunnel conveyors at a slaughtering rate of 600 pigs/hour. As a high level a flow velocity 0.12 m/s is selected. The course of the chilling process is here determined primarily by the thermal properties of the dummy (carcass), as the heat-transfer coefficient is higher than 500 W/m^2K.

The effect of the temperature of the chilling medium is examined at a high and at a low level. The low level -8 °C is determined with a view to achieving a limited shell freezing. The high level is selected with a view to avoiding shell freezing, which may already start at approx. -2 °C. However, it is necessary to take the handling of slush ice into consideration, and as a compromise -4 °C has therefore been selected as a high level.

Three levels of ice content are used. Gibb's phase rule lays down two degrees of freedom in the state of equilibrium of the slush ice. Thus, it is not possible freely to specify temperature and ice content by a certain ethanol concentration. At the low level the ice content is 0 weight percent (=brine). A mixture with 25 weight percent ethanol is used (frost proof to -15 °C). As a middle level an ice content of 15 weight percent is selected. By the high level the ice content is 25 weight percent, as a higher ice content causes a drastic increase of the viscosity, and there is a risk that the ice will get lumpy.

The following concentrations of ethanol are used, which will make the wanted combinations of temperature and ice content possible:

Temperature (°C)	Ice Content (%)	Ethanol (%)
-3.8	15	7
-4.2	25	7
-8.0	25	12
-8.2	15	14

The cooling of the dummy takes place in a chilling vessel containing brine or slush ice which is circulated in an external refrigeration circuit. The flow volume to the chilling vessel is measured, and the inlet valve or the speed of rotation of the pump is adjusted, so that the flow volume ensures the desired flow velocity in the vessel.

The heat transfer from the dummy to the chilling medium is registered by means of thermo-detectors in the dummy. The readings registered are subjected to a statistical analysis to determine which effect a change of the parameters has upon the mean heat flux (mean heat flux is defined by the proportion between the removed quantity of energy and the process time in the chilling vessel). Main actions and interactions are examined by multi variance analysis.

1. Flow Velocity

The statistical analysis shows that a change of the flow velocity is not significant for the course of the chilling process when the flow velocity is in the interval of 0.05 m/s to 0.12 m/s. Thus, the chilling vessel can be designed in a fairly simple way, and there is no need for special arrangements in order to provide high flow velocities.

2. Ice Content

At a temperature of -8 °C for the chilling medium the analysis shows that the ice content is only significant for the course of the chilling process when the ice content is between 0 and 15 weight percent. The average flux is 292 W/m^2 at 0 weight percent ice content, whereas

it is 337 W/m^2 at 15 weight percent ice content. If the content of ice in the slush ice is increased from 15 to 25 weight percent, no appreciable change in the flux is achieved. The results show that there is a certain degree of shell freezing. A certain portion of ice increases the heat-transfer coefficient, but this proportion does not change significantly in the interval between 15 and 25 weight percent ice content. Thus, by use of slush ice with between 15 and 25 weight percent ice it is possible to reduce the process time by approx. 15 % compared with the use of a corresponding ethanol-based brine (0 % ice content).

At a temperature of -4 °C for the chilling medium there is no appreciable effect from changing the ice content. Identical chilling times are achieved. It may be because there is no substantial shell freezing. An improvement of the heat-transfer coefficient beyond 500W/m^2K does not reduce the chilling time appreciably, as the thermal resistance to heat transfer becomes the dominant factor.

3. Temperature

The analysis shows that the temperature of the chilling medium is significant for the course of the chilling process. A reduction of the temperature from -4 to -8 °C increases the mean flux by approx. 20% both for slush ice and for brine. It is likely that a further reduction of the chilling time can be achieved by reducing the temperature of the chilling medium even more, but this will increase the shell freezing and the risk of deterioration of the meat quality. Moreover, the energy consumption will rise. For a typical screw compressor the energy consumption will rise by 10-12 % when the suction temperature is reduced from -15 to -18 °C. Moreover, the initial expenditure will rise because the capacity of the compressors is reduced.

4. Process Times

The examination shows that with brine or slush ice of -4 °C the times for chilling from slaughter-warm state to an average temperature of 5 °C may be expected to be approx. 70 minutes for pig carcasses weighing 74 kg. For brine of -8 °C a process time of approx. 60 minutes may be expected. Slush ice of -8 °C with an ice content of between 15 and 25 weight

percent provides the quickest chilling process. The process time may be expected to be approx. 50 minutes.

Thus, chilling of half carcasses by means of a chilling medium in the form of brine or slush ice provides attractive process times by a temperature of the chilling medium in the interval between -4 and -12 °C.

Example 3

Comparison with traditional tunnel chilling

This example serves the purpose of comparing the chilling of the invention in brine or slush ice with traditional tunnel chilling of half pig carcasses.

It is assumed that the pig carcasses are carcasses weighing 75 kg being conveyed on a slaughtering line with a slaughtering capacity of 600 pigs/hour. Thus, the need for cooling capacity is 1700 kW which includes the chilling need and system loss.

1. Tunnel Chilling

The tunnel chilling system used for traditional tunnel chilling with air as chilling medium comprises a two-stage ammonia refrigerator. The low-pressure part includes tunnel vaporizers, screw compressors, piston compressors, a low-pressure separator, pipes and valves. The compressors have a chilling power of 1700 kW at a suction temperature of the low pressure equipment of -35 °C and a suction temperature of the high pressure equipment of -10 °C. The high-pressure part includes screw compressors, piston compressors, an inter-mediate cooler, condensers, recipients, pipes and valves. The compressor capacity on the high-pressure side is 2200 kW at -10 °C/35 °C. The area of the vaporizer varies according to the location in the tunnel, i.e. there are smaller but more vaporizers at the beginning of the tunnel, whereas the vaporizer area has been doubled at the end of the tunnel, while the number of vaporizers has been reduced proportionally.

The half pig carcasses are chilled from a slaughter-warm state to a mean temperature of 7 °C in 70 minutes. The chilling loss is 0.8 % of the carcass weight. The required area for a chilling tunnel is approx. 0.7 m^2/pig. The system has a high consumption of power to run compressors and ventilators in the tunnel.

2. Chilling with Brine

The chilling system which is used to chill half carcasses by means of brine includes a one-stage ammonia refrigerator, comprising a plate heat exchanger, screw compressors, piston compressors, liquid separator, condensers, recipient, pipes and valves. The total cooling capacity of the compressors is 1700 kW at -15 °C/35 °C.

The brine consists of a mixture of 25 weight percent ethanol and 75 weight percent water, contained in a chilling vessel. By means of the refrigerator the brine is kept at a temperature of -8 °C. After the half carcasses have been enveloped in a foil, they are immersed into the chilling vessel, which contains 700 m^3 brine. Approx. 5 m^3 of brine is circulating in the refrigerator.

Measurements show that it is unnecessary to use pump energy to create circulation of the brine in the vessel. The pumps of the system shall only supply cold brine to the vessel corresponding to the need for cooling.

The heating of the brine in the vessel is assumed to be 2 °C. The pumps circulate 720 m^3 brine per hour. The pressure loss in the system is estimated to be a maximum of 30 mWC. Two pumps are used, with a total power consumption of approx. 90 kW.

The brine is cooled in the refrigerator from -6 to -10 °C. In a mixing loop half the quantity of return brine is circulated, i.e. 360 m^3/hour. The pressure loss in the mixing loop and the plate heat exchanger is put at 15 mWC. A pump with a power consumption of approx. 25 kW is used.

The carcasses are chilled to an average temperature of 7 °C in 59 minutes. The required area is only 0.4 - 0.5 m^2/pig carcass, as the chilling process is faster than tunnel chilling. The one-stage system only requires half the space in the machine hall.

3. Chilling with Slush Ice

The chilling system used for chilling of half carcasses by means of slush ice comprises a one-stage ammonia refrigerator, constructed from a slush-ice generator, a slush-ice container, screw compressors, piston compressors, liquid separator, condensers, recipient, pipes and valves. The total refrigerating capacity of the compressors is 850 kW at the operating point of -15 °C/35 °C. The slush ice is produced in a slush-ice generator with a capacity of 850 kW.

The slush ice is produced on the basis of 12 weight percent ethanol and 88 weight percent water. The slush ice is led to a chilling vessel, which contains 700 m^3 slush ice. Approx. 10 m^3 slush ice is circulating in the slush-ice refrigerator and buffer tank.

For the production of slush ice is used a generator with mechanical stirring to prevent ice particles from freezing on to the wall between the primary and secondary cooling medium. The amount of power used for stirring in the generator corresponds to approx. 10% of the chilling power.

Because of the high cooling capacity in the ice of the slush ice, a large proportion of the required cooling can be produced and accumulated during the low-rate hours of the power station. The accumulated cooling quantity is used in the daytime during the working period. The slush ice must be stirred during storage. The energy used for the stirring process, done by means of propellers, is approx. 1 % of the cooling power, i.e. approx. 20 kW.

The slush ice is supplied to the chilling vessel with 25 weight percent ice content and is removed with 15 weight percent ice content. Thus, 130 m^3 slush ice per hour must be circulated.

Slush ice with 25 weight percent ice content is more viscous than a brine, and the pressure loss in pipes is typically 3-4 times higher at the same flow velocity. At a relative flow velocity of 0.05 m/s or less, the same pressure loss in the system can be expected as in use of brine.

The carcasses are chilled to a mean temperature of 7 °C in 49 minutes. The chilling loss is 0 %. The one-stage system only requires half the space in the machine hall.

4. Calculations

Based upon the above assumptions, calculations show that investments in the brine chilling system and the slush-ice chilling system are approx. 30% lower than an investment in the tunnel chilling system.

The operating costs are only approx. 1/4 of the costs running a tunnel chilling system. The electricity costs are an essential part of the operating costs. They have been reduced to half in the brine system and to one third in the slush-ice system.

Brine chilling reduces the process time from 70 to 59 minutes. In slush-ice chilling the process time is reduced to 49 minutes.

In the brine system and slush-ice system the chilling loss is 0 %, as the envelopment into foil prevents the carcass from giving off moisture.

Thus, the analysis shows that compared with the tunnel chilling used today, very significant savings in electricity costs, a reduction of the process time, and a reduction of the weight loss can be achieved in using a chilling medium in the form of brine or slush ice.

The use of slush ice as a chilling medium is economically more attractive than chilling with brine.

Example 4

Compositions of Slush Ice

This example specifies suitable compositions of slush ice.

The slush ice which is used in the method of the invention is appropriately based on a compromise between the ice content and the viscosity at the operating temperature. At an operating temperature of between -4 °C and -6 °C fairly weak concentrations of the freezing-point-reducing substance can be used, e.g. 2-15 weight percent ethanol, propylene-glycol or NaCl.

Measured properties for different mixtures of slush ice will appear from the table below.

Additive	**Weight-%**	**Start temp. for ice formation *) (°C)**	**Temperature fall by ice content **) (°C)**	**(%)**
NaCl	2	-1.6	0.2	50
	4	-3.0	1.0	50
	6	-4.5	1.2	40
Ethanol	3	-1.2	0.5	40
	6	-2.5	0.5	40
	10	-4.2	0.6	40
Propylene-glycol	6	-1.6	0.4	40
	10	-2.6	0.5	35
	15	-4.1	0.9	35

*) ±0.5 °C

**) ±10%

The change in temperature by the phase change of ice to water is identical for all three types.

At a certain desired freezing point NaCl gives the most aqueous mixture.

Calculated values for density, dynamic viscosity and heat conductivity for mixtures with freezing point in the interval -4 to -5 °C show that slush ice based on NaCl has the best thermo-physical properties (heat-transfer coefficient, cooling capacity, etc).

The latent cooling capacity per kg slush ice is a direct function of the ice content. For the sake of the dynamic viscosity it is most practical to use slush ice with an ice content of below 35 weight percent, especially below 30 weight percent.

Example 5

Pre-tests

In order to examine which influence the temperature of the chilling medium may have on the chilling process, tests are carried out at a slaughterhouse chilling half pig carcasses by means of brine with temperatures of -2 ^{0}C, -8 ^{0}C and -15^0 C. The carcasses are each put into a plastic bag, which is evacuated and sealed, and then the enveloped carcasses are submerged into the cold brine for chilling. After the carcasses have been lifted from the brine again and the plastic bag has been removed, the temperatures of the half carcasses are equalized for 16-20 hours in a cold-storage room to an average temperature of 7 ^{0}C. The tests show that discoloration of the outer fibres of meat may occur at -8 ^{0}C and -15 ^{0}C, especially on the ham and loin. The reason is a combination of high water activity (relative humidity in the surface) and shell freezing. The plastic bag prevents the water from evaporating from the surface.

At a chilling medium temperature of -2 ^{0}C there is no shell freezing and no discoloration. Therefore, it has been decided to carry through the actual tests at this temperature of chilling medium. Model calculations give a chilling time of 90 minutes for an average carcass weight of 75 kg. Within this space of time the temperature of the carcass will be reduced from slaughter-warm state to an average 7 ^{0}C.

Comparative tests

The purpose of these tests is to compare the method of the invention with batch chilling. For comparison, measuring results from a tunnel chilling process are also given.

The method of the invention is performed with test equipment set up at a slaughterhouse. The equipment comprises a vessel containing brine with 18.5 weight percent bacon brine salt. The solution is kept cooled at -2 ^{0}C. Half pig carcasses are each packed in a plastic bag, which is fitting closely to the surface of the carcass by evacuating the atmospheric air from the bag. The bag is sealed, and the enveloped, slaughter-warm carcasses are submerged into the cold brine for 90 minutes. After the chilling process, the half carcasses are lifted from the vessel, the bags are removed, and the carcasses are conveyed into the cold-storage room of the slaughterhouse, which serves as a temperature-equalization room. The temperature in the room is -1 ^{0}C.

Batch chilling is carried through in the cold-storage room of the same slaughterhouse. The usual programme of the slaughterhouse for batch chilling is used for chilling and equalization of half pig carcasses. Results from the tunnel chilling system of another slaughterhouse is used for comparison.

For the present test a total of 53 pig carcasses is removed from the slaughter line. The carcasses are selected on the basis of normal meat quality ($6.3 < pH_1 < 6.8$), a meat percentage between 58 and 65, and a slaughtered weight between 70 and 80 kg. An equal distribution of sows and castrates is provided.

One half carcass is chilled in brine and subsequently equalized in the cold-storage room for approx. 18 hours. The other half carcass is batch chilled for approx. 20 hours in the cold-storage room.

At the tests, the drop in temperature, the drop in pH, and the chilling loss are recorded.

Drop in Temperature

The drop in temperature is recorded by means of insertion probes, which are inserted to the centre of the ham at the thigh-bone, to the centre of the loin at the 4th and 5th vertebrae at a depth of 5 cm, to the centre of the loin at the 7th and 8th vertebrae at a depth of 5 cm, and in the fore-end at the shoulder blade.

The recorded values of temperature and time are processed statistically and analytically.

The tests show that the drop in temperature in the first five hours is considerably faster when the carcass is chilled with brine. The difference is especially distinct for the loin muscle, the muscle which is most easily affected due to the short distance to the thermic centre.

Statistical processing of the drops in temperature, adjusted for biological variation in meat percentage and weight, shows that chilling with brine gives a heat transfer which is 3 times higher than the heat transfer for batch chilling, and 1.5 times higher than the heat transfer for tunnel chilling (average air velocity 4 m/s).

The temperature development in the loins corresponds to a very "harsh" tunnel chilling process with a traverse time of under 60 minutes, an air temperature of -25/-27 ^{0}C, and an average air velocity of 4 m/s.

The method of the invention uses a chilling medium (brine) with almost the same temperature as the temperature of the cold-storage room, but the chilling time is only 90 minutes, i.e. 1/4 of the process time for batch chilling, which is 6 hours.

As regards time, the present chilling method, which uses brine with a temperature of -2 ^{0}C, can be compared with a one-stage tunnel chilling process with an air temperature of -18 ^{0}C. In the first case the evaporation temperature of the refrigerator is -7 ^{0}C, and in the second case -25 ^{0}C.

The COP-value (kW-chilling/kW-power consumption) is 2.6 for the tunnel chilling and 4.9 for chilling with brine, which means that the energy consumption of the compressors can be reduced by approx. 50% by use of brine for chilling.

The total energy consumption in tunnel chilling is typically 2.7 kWh per pig carcass, whereas the corresponding consumption in chilling with brine of a temperature of -2 ^{0}C, based on the test results, is estimated to be 1.45 kWh per pig carcass. Thus, the tests confirm that the energy consumption can typically be reduced by approx. 50% in comparison with the tunnel chilling used today.

Drop in pH

The pH of the meat is recorded by means of electrodes which are inserted into loin and silverside. pH is measured 1, 2½, 4, 5, 6 and 24 hours after the sticking. pH is also measured in neck fillet and top round 24 hours after the sticking.

The tests show that the pH-drop in loin and silverside takes place at a slower rate in chilling with brine than in batch chilling. After approx. 90 minutes in the chilling vessel the pH is on average 0.15 higher than in batch chilling. In the space of time 1½ to 5 hours after the slaughtering, the drop rate in pH is the same by the two chilling methods. After 24 hours the pH is still higher in carcasses which have been chilled by means of brine, but it comes closer to the pH of meat which has been batch chilled.

Chilling loss

Chilling loss is defined as the percentage weight loss of the carcasses from slaughter-warm state to temperature-equalized state. The slaughter-warm pig carcasses are weighed prior to the chilling process and then weighed again the next morning after the equalization process. The table below shows the average chilling loss recorded on the basis of 53 measurements.

Chilling method	Chilling loss	Level of equalization
Batch chilling	1.89 weight percent	1 ^{0}C
Chilling with brine	0.99 weight percent	1 ^{0}C

As the plastic bag prevents loss of water from the surface of the carcass, the chilling with brine gives a high water activity of the surface. The carcass contains between 800 g and 1000 g more water than the corresponding sides of carcass which are batch chilled. The higher water activity is retained during the equalization process.

In order to reveal which losses are caused by the enveloping and the evacuation, the pig carcasses are weighed before and after the chilling in the vessel. The weight loss is measured to be approx. 60 g (less than 0.05 weight percent). The weight loss is supposed to be due primarily to loss of loosely attached remains from the splitting process and secondarily to extraction of fluid caused by the evacuation.

After the equalization, the temperature of the carcasses is approx. 1 ^{0}C, which is 4 ^{0}C lower than desired for practical purposes. The low temperature is due to the fact that the air and temperature conditions in the available equalization room could not be accommodated in the tests, since the room is used in the daily operation of the slaughterhouse.

If the after-cooling in the equalization period is adjusted to 2 ^{0}C, the total chilling loss can for practical purposes be expected to be only approx. 0.3 to 0.4 % in the method according to the invention.

Example 6

Modified method

In order to avoid the risk of discoloured patches on the surface of the meat at temperatures which cause shell freezing of the carcass, a modified chilling process is applied, in which the carcass is first dried (e.g. cooled in an air lock with cold and dry air, which will reduce the

water activity of the surface). For example, the humidity of the surface may be reduced to 70 weight percent. Afterwards, the actual chilling process is performed with a chilling medium (brine or slush ice) which has a temperature of e.g. -8 ^{0}C.

The water activity of the surface is recovered during the temperature equalization. Therefore, the total chilling loss of the process is not increased.

Such a modified chilling process, using air at first and then a chilling medium in the form of brine or slush ice, can reduce the process time without any risk of formation of discoloured patches.

Claims

1. Method for chilling of carcass parts after slaughtering, **characterized** in that the carcass parts are submerged into a liquid chilling medium with a temperature below 0 ^{0}C, that a relative movement between the chilling medium and the carcass parts is provided, and that the carcass parts, after having given off a desired quantity of heat to the chilling medium, are lifted from the chilling medium and then allowed to equalize differences in temperature.

2. Method according to Claim 1, **characterized** in that the temperature of the chilling medium is -1 ^{0}C or below, preferably between -2 and -20 ^{0}C.

3. Method according to Claim 1, **characterized** in that the temperature of the chilling medium is -2 to -4 ^{0}C, and that the velocity of the relative movement is set to mainly prevent shell freezing.

4. Method according to Claim 1, **characterized** in that the temperature of the chilling medium is between -4 and -12 ^{0}C to provide shell freezing.

5. Method according to Claim 1, **characterized** in that the velocity of the relative movement between 0.02 and 1 m/s is used, which velocity is preferably provided by leading the carcass parts, suspended from a suspension conveyor, through a vessel containing the chilling medium.

6. Method according to Claim 1, **characterized** in that the carcass parts, before they are submerged into the chilling medium, are enveloped individually in a foil which is drawn closely to the surface of the part by evacuation of air from inside the foil.

7. Method according to Claim 6, **characterized** in that the surface of the carcass parts is exposed to partial drying prior to being enveloped in a foil, and that the chilling in the chilling medium takes place under such conditions that the carcass parts are shell frozen.

8. Method according to Claim 1, **characterized** in that slush ice is used as chilling medium with an ice content of max. 35 weight percent, especially 10-30 weight percent.

9. Method according to Claim 1, **characterized** in that the chilling medium contains NaCl which constitutes more than 15 weight percent when the medium is a brine and 2 to 15 weight percent when the medium is slush ice.

10. Method according to Claim 1, **characterized** in that the chilling medium contains 5 to 25 weight percent ethanol.

11. Method according to Claim 1, **characterized** in that the chilling medium is cooled down in a one-stage refrigerator.

12. Method according to Claim 1, **characterized** in that it is carried out under such conditions that an external heat-transfer coefficient for the carcass parts of between 150 and 2500 W/m^2K is provided, preferably between 300 and 1000 W/m^2K.

13. Method according to Claim 1, **characterized** in that the carcass parts are shell frozen pre-rigor to a given maximum depth.

14. Method according to Claim 1, **characterized** in that the chilling of the carcass parts in the chilling medium continues after the equalization (post-rigor) until the parts are frozen through.

15. System for chilling of carcass parts after slaughtering, **characterized** in that it comprises a vessel, means of transportation to lower into the vessel carcass parts being conveyed along a transport path, means of transportation to provide a relative movement between the carcass parts and a liquid chilling medium in the vessel, a refrigerator designed to cool the chilling medium, means of transportation to lift the carcass parts from the vessel, and means of transportation to convey the carcass parts to an area designed for temperature equalization of the carcass parts.

16. System according to Claim 15, **characterized** in that the means of transportation to provide a relative movement between the carcass parts and a liquid chilling medium in the vessel comprise a conveyor which carries the carcass parts through the vessel.

17. System according to Claim 15, **characterized** in that it comprises an arrangement which, before the carcass parts are lowered into the vessel, envelops each carcass part into a foil and draws the foil closely to the surface of the part by evacuating the air from inside the foil, and another arrangement which removes the foil from the carcass part after it has been lifted from the vessel.

18. System according to Claim 17, **characterized** in that up-stream of the arrangement it comprises an equipment for partial drying of the carcass parts which are being conveyed along the transport path.

19. System according to Claim 15, **characterized** in that the refrigerator for cooling down of the chilling medium is a one-stage refrigerator.

20. System according to Claim 15, **characterized** in that the vessel contains a brine on an aqueous basis or slush ice as chilling medium for the carcass parts.

21. System according to Claim 15, **characterized** in that it comprises a slush-ice generator.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK 98/00464

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: A23B 4/08, A23L 3/375
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: A23B, A23L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4367630 A (BERNARD ET AL), 11 January 1983 (11.01.83), column 2, line 9 - line 13, abstract --	1-2,4,6-7, 11,15-19
A	US 3874186 A (BONUCHI ET AL), 1 April 1975 (01.04.75), column 7, line 49 - line 57, abstract --	1-21
A	US 4860554 A (INNES ET AL), 29 August 1989 (29.08.89), column 1, line 5 - column 2, line 46 --	1-21
A	WO 9627298 A1 (DANSK TEKNOLOGISK INSTITUT), 12 Sept 1996 (12.09.96) --	1-21

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT
Information on patent family members

21/12/98

International application No.
PCT/DK 98/00464

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